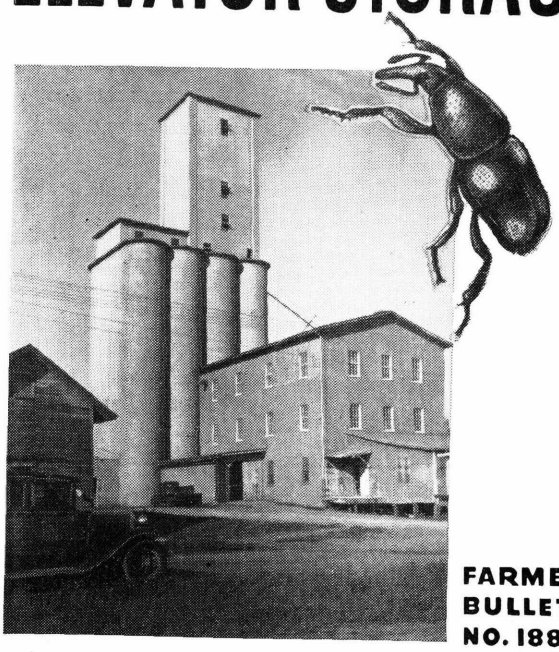
Control of INSECT PESTS of GRAIN in ELEVATOR STORAGE



FARMERS' BULLETIN NO. 1880

U. S. DEPARTMENT OF AGRICULTURE

EACH YEAR many million bushels of grain are placed in storage in terminal elevators. The problem of protecting this grain from insect damage is a serious one, since infestation originating in the field, in farm or country elevator storage, or in railway boxcars in which the grain is carried may increase to dangerous proportions after the grain reaches the terminal elevator.

The many facilities of the modern elevator for handling and treating grain and observing changes in its physical condition that may be employed to simplify the task of keeping the grain in condition are discussed in this bulletin.

Hydrocyanic acid, chloropicrin, and mixtures of ethylene dichloride or carbon disulfide with carbon tetrachloride are the fumigants most frequently used for treating infested grain in elevator storage. Information regarding these fumigants and directions for their use are given.

This bulletin supersedes the portions of Farmers' Bulletin 1483 pertaining to insect pests of grain stored in country or terminal elevators and warehouses.

Farmers' Bulletin 1811 supersedes the other portions of Farmers' Bulletin 1483; namely, those that relate to the control of insects in farm-stored grain.

Washington, D. C. Issued August 1941

CONTROL OF INSECT PESTS OF GRAIN IN ELEVATOR STORAGE

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Contents

MANY MILLION bushels of grain are placed on the market and find their way to terminal elevators each year. From one year to another the crop varies in quality and in the condition in which it enters storage. The safe storage of this grain presents a problem that challenges the ingenuity and resourcefulness of the elevator operators. Nevertheless, with the many facilities of the modern elevator for handling and treating the grain and determining changes in its temperature and moisture the experienced operator has little difficulty in keeping grain in good condition. As the condition of grain changes, its susceptibility to insect attack also varies. A discussion of some of the factors influencing insect infestation of grain in elevator storage follows, together with recommendations for the prevention or control of the insects involved.

INSECTS THAT CAUSE TROUBLE IN ELEVATORS

Although many species of insects attack dried vegetable materials of all kinds, only a few of these are primary pests of stored grain that is in good condition. In terminal elevators the rice weevil (*Sitophilus oryza* (L.)) (fig. 1), the granary weevil (*S. granaria* (L.)) (fig. 2), and the lesser grain borer (*Rhizopertha dominica* (F.)) (fig. 3) are the worst offenders. These insects are capable of boring into sound grain, and their initial attack opens the way for others that are unable to cut their way through the tough seed coat.

Infestations of the Indian-meal moth (*Plodia interpunctella* (Hbn.)) (fig. 4) and other moths sometimes occur on the surface of stored grains, and a matting of silk spun by these insects sometimes covers the entire surface. The moths are unable to make their way into the

binned grain; hence injury from this insect does not usually extend far below the surface. In some sections of the country the Angoumois grain moth (*Sitotroga cerealella* (Oliv.)) is a serious pest of wheat before it is threshed and binned, but its damage to grain in elevator storage is negligible.

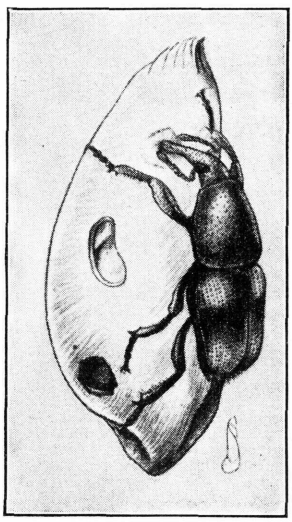

FIGURE 1.—The rice weevil is the worst pest of stored grain.

The flour beetles (*Tribolium confusum* (Jacq.-Duv.) and *T. castaneum* (Hbst.)) and numerous other beetles known to the trade as "bran bugs" are secondary pests insofar as the elevator is concerned, but their presence in wheat is of vital importance to the miller who is the ultimate processor of the grain. Studies of insect infestation in flour mills indicate that incoming infested grain is the most important source of infestation in flour mills. In a survey conducted over a 2-year period, during which monthly collections were made from 17 flour mills scattered over the southwestern milling area, it was found that 82.3 percent of the samples of screenings from incoming grain were infested with an average of 38.6 insects per 8-ounce sample. Some 30 different species of insects were taken in these samples, but the flour beetles were numerically more abundant than all other species combined.

For brief accounts of the life histories and habits of the insects that infest stored grain, together with illustrations of the more destructive forms, the reader is referred to Farmers' Bulletin No. 1260 of the United States Department of Agriculture, Stored-Grain Pests.

FIGURE 2.—The granary weevil is common in elevator storage.

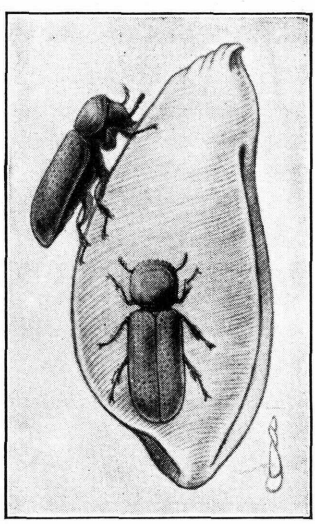

FIGURE 3.—The lesser grain borer has in recent years become exceedingly common in stored grain in elevators.

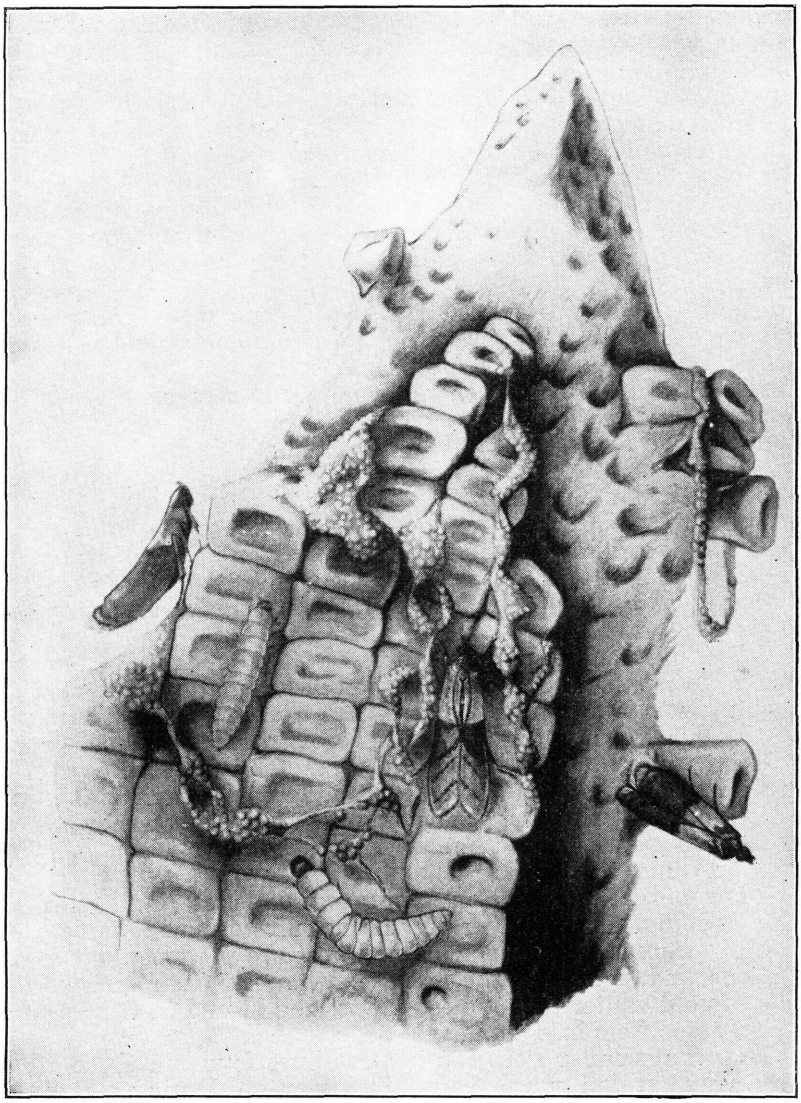

FIGURE 4.—The Indian-meal moth sometimes webs the grain on the surface of elevator bins, forming a dense silken mat.

SOURCES OF INFESTATION

Infestation in stored grain may originate from several sources—in the field, in storage on the farm, in line or country elevators, or in boxcars while in transit.

In some grain-growing regions infestation starts in the field before the crops are harvested. This is, of course, particularly true in the southern part of the country, where the rice weevil and other insects are abundant in the field at harvesttime, and in the soft red winter wheat region of the Eastern States, where the Angoumois grain moth frequently causes enormous losses.

Many of the insect pests of stored grain are of tropical or subtropical origin and fortunately are unable to survive in the field in those portions of the country where severe winters prevail. Nevertheless, many insects winter over in the Northern States in barns, granaries, and elevators, where they are protected from extreme winter temperatures. The congregation of large numbers of insects in stored grain often causes it to heat, so that insects located in these "hot spots" are not only protected from the cold but are able to continue active breeding and feeding throughout the winter. Some of these overwintering insects later fly to the fields and lay their eggs in or on the ripening grain.

In the soft red winter wheat region of Pennsylvania, New Jersey, Delaware, Maryland, Virginia, and North Carolina field infestation of wheat by the Angoumois grain moth occurs each year. Development is rapid in the unthreshed grain, and in outbreak years infestation may reach as high as 90 percent late in September, if the grain is left unthreshed as long as that. Outbreaks of this insect occur when weather conditions are particularly favorable. A warm winter favors the survival of large numbers. When this is followed by hot weather from June to October, the field infestation is likely to build up into outbreak proportions unless grain is threshed promptly after harvest. Severe winters greatly reduce the numbers of hibernating insects, and the occurrence of an outbreak of the Angoumois grain moth after a hard winter is extremely unlikely.

The limiting effect of severe winters on the abundance of insects in stored grain is reflected in the condition of grain grown and stored in the spring wheat region of the Northern States. Grain arriving on the Minneapolis market from this region is rarely infested. Inspection records indicate that in average years less than 1 percent of the cars of grain arriving on this market grade weevily even in the worst months, and it is quite likely that some of the infestation shown occurs in wheat shipped from the Southwest or in spring wheat held over from a previous year.

The low moisture content of grain grown under semiarid conditions is also an important factor in preventing infestation in stored grain. The white wheats of the Pacific Northwest are produced under such conditions, and, because of the dryness of the grain, combined with the effects of cold winters, the wheat grown and stored in this region is singularly free from insect damage.

A somewhat similar situation is sometimes found in the hard red winter wheat region of the Great Plains area. During a period of successive drought years insect infestation in stored grain falls to a minimum. Such a condition existed during the years 1934 to 1936. Wheat arriving on the Kansas City market during this time showed a progressively decreasing degree of infestation until the period from July 1936 to June 1937, during which infestation did not reach 1 percent of the cars received in any one month. In contrast to this condition, rainy weather persisted throughout the harvest season in Kansas during the summer of 1939, and much wheat went into storage with a moisture content of 14 percent or more. In this condition it was very susceptible to infestation by insects, and during November the Agricultural Marketing Service reported that 33 percent of 1,147 cars of grain arriving on the Kansas City market were weevily. This infestation, which is the worst on record for this section of the country

during the last 20 years, was not caused by field infestation, since field surveys of the standing grain at harvesttime revealed no evidence of infestation by the insects that attack stored grain.

Storage on the farm for short periods in bins which are rarely cleaned, which harbor insects from year to year, and which are located near supplies of infested feed or screenings is likely to result in infestation of the grain. It is not unusual to find from 90 to 100 percent of farm bins infested wth insects during outbreak years. Further storage for short periods in small line or country elevators, poorly equipped for handling and treating grain, provides one more source of infestation before the grain reaches the terminal elevator. The hazard of farm or country elevator storage to wheat is shown by the inspection records of wheat arriving on the market at different times of the year at some of the points in the main wheat-growing regions of the country. In general, wheat arriving on the market in June, July, and August, with the first rush of newly harvested grain, shows little visible infestation. After August, however, the increasing percentage of cars of wheat grading weevily indicates the effect of short periods of storage on farms or in country elevators.

Railway boxcars used for transporting grain are likely to carry large populations of the insects that attack grain, concealed in cracks and crevices and breeding in accumulations of waste grain and milled products that have become lodged behind the grain linings, particularly at the ends of the cars. Infestation of grain shipments is bound to take place in such cars.

The arrival of infested grain at terminal elevators affords the opportunity for insects to spread to clean grain already in storage there.

CONTROL OF INSECTS IN TERMINAL ELEVATORS

With the equipment of the modern elevator (fig. 5), a number of methods can be utilized to keep grain in condition and minimize or prevent loss from insect damage. Cleaning machinery can be relied upon to remove many insects and damaged kernels. All screenings and grain cleanings that contain living insects should, of course, be disposed of in such a manner as to prevent these insects from becoming a menace to other grain. The most efficient machinery, however, will not remove all the free living insects from the grain or the immature stages that live within the grain itself. Other methods, such as the application of cold, heat, and fumigants, must therefore be employed.

USE OF LOW TEMPERATURES

The insect pests of stored grain are not active at temperatures below 50° F.; hence, if grain can be cooled sufficiently, further injury will be prevented so long as such temperatures are maintained. During periods of cold weather grain can be cooled by transferring it from one bin to another, dropping it through the chilled air or running it over a series of baffles in the process. If the weather is cold enough, this method of treating grain is one of the cheapest and most effective methods that can be employed. The temperature of the grain cannot be lowered many degrees by a single turning or transfer unless the difference between the temperature of the grain and that of the air is considerable and the exposure to the cold air is prolonged by slowing

down the movement of the grain. Oftentimes, however, even though the general temperature of the grain is not greatly lowered, turning the grain will break up colonies of insects and, by mixing the warm and cool portions of the grain, improve the temperature of the grain as a whole.

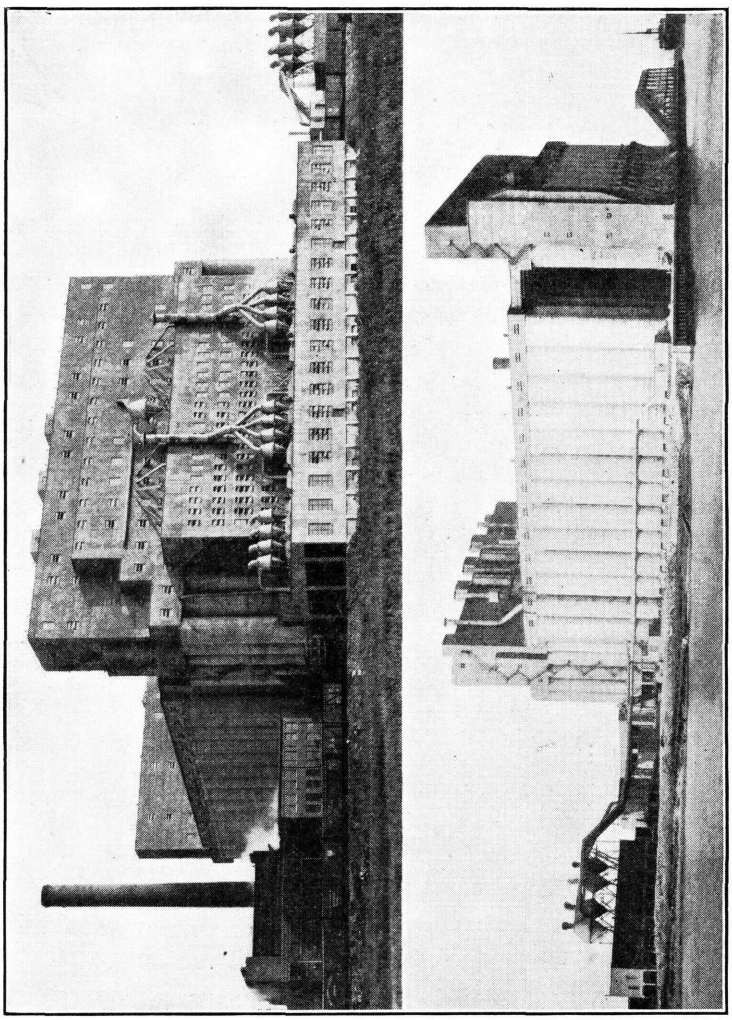

FIGURE 5.—Two views of a modern grain elevator of 10,000,000 bushels capacity. This elevator is equipped for drying and heating grain and is well designed for treating grain by the most up-to-date methods.

The changes in the temperature of grain as the result of transferring it from one bin to another in cold weather are illustrated in figure 6. This chart, based on a chart published by William Robinson in 1926,[1] shows that by turning the grain once in November and again in January the temperature of the grain was brought down to

[1] ROBINSON, WILLIAM. LOW TEMPERATURE AND MOISTURE AS FACTORS IN THE ECOLOGY OF THE RICE WEEVIL, SITOPHILUS ORYZA L., AND THE GRANARY WEEVIL, SITOPHILUS GRANARIUS L. Minn. Agr. Expt. Sta. Tech. Bul. 41, 43 pp., illus. 1926. See figure 23.

a point where it could be stored safe from damage by insects, although the temperatures obtained were not low enough to cause the death of insects. If the grain had been turned more frequently or exposed more to the cold by "high-lining," or running over baffles, it is likely that it could have been cooled to a point where all insect life would have been killed.

The insect pests of stored grain are mostly of subtropical origin and do not hibernate. In their native habitat they have never had to adapt themselves to low temperatures, consequently they have developed no great resistance to cold. However, they are rarely exposed to extremes of low temperature, as grain in storage is a poor conductor of heat. It both absorbs and gives off heat slowly and usually remains all winter above the freezing point of water.

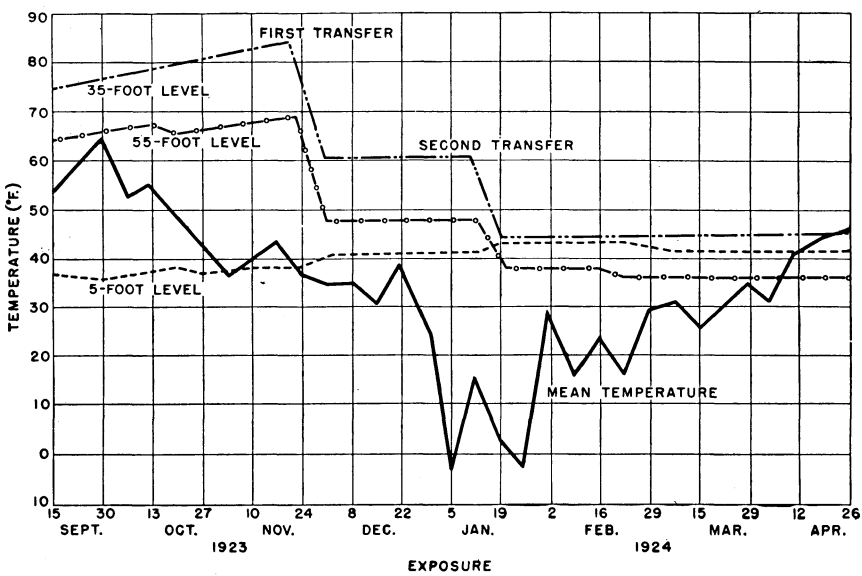

FIGURE 6.—Temperature changes in wheat near the top, bottom, and middle of a 60-foot bin, as influenced by transferring grain to other bins during periods of cold weather.

The rice weevil is dormant at temperatures of 45° F. or below, and the granary weevil at 35° or below. If the temperature of grain infested with these weevils can be kept below 35° F. for some time, these insects will eventually die. Since these weevils do not hibernate, their life processes are not sufficiently retarded by low temperatures to allow the food reserves of their bodies to carry them through an extended period of dormancy; therefore they die from starvation in a comparatively short period. A few of the insect pests of stored grain, such as the cadelle, do hibernate and are capable of surviving exposure to low temperatures for long periods. To be quickly effective against all grain-infesting insects, temperatures must be especially low. Some idea of the relative resistance of various stored-grain insects to low temperatures can be obtained by reference to table 1.

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TABLE 1.—*Resistance of various insects that attack stored grain to low temperatures*

Insect	Days of exposure required to kill all stages at—						
	0° to 5° F.	5° to 10° F.	10° to 15° F.	15° to 20° F.	20° to 25° F.	25° to 30° F.	30° to 35° F.
Rice weevil (*Sitophilus oryza*)	1	1	1	3	6	8	16
Granary weevil (*S. granaria*)	1	3	-------	14	33	46	73
Saw-toothed grain beetle (*Oryzaephilus surinamensis*)	1	1	3	3	7	23	26
Confused flour beetle (*Tribolium confusum*)	1	1	1	1	5	12	17
Red flour beetle (*T. castaneum*)	1	1	1	1	5	8	17
Indian-meal moth (*Plodia interpunctella*)	1	3	5	8	28	90	-------
Mediterranean flour moth (*Ephestia kuehniella*)	1	3	4	7	24	116	-------

PREVENTION OF HEATING OF GRAIN BY INSECTS

At times stored grain suffers considerable damage from heating, or "bin burn," that may be attributed in part to the activities of insects. The body temperature of insects normally follows pretty closely that of their environment, but when they are active their temperature rises. The production of both heat and moisture is an end product of respiration or oxidation of the body tissues of the insects, and when large numbers of these insects cluster in bins of grain the excess heat and moisture produced by them are absorbed by the surrounding grain, and "hot spots" are produced. This increase in temperature and moisture content of the surrounding grain causes a corresponding increase in the respiration of the grain. The biological oxidation of the carbohydrates of the wheat kernels produces added moisture and heat, consequently the combined action may result in serious bin burn unless the hot spots are broken up. This can usually be accomplished by turning the grain, unless the infestation of insects is too extensive and the general temperature of the grain and air too high. In that case fumigation must be resorted to. It has been found that killing the insects by fumigation results in a return of the temperature of the grain to normal unless other factors are causing the heating. There are, of course, factors other than insect infestation that may cause the heating of grain.

DRYING AND HEAT STERILIZATION OF GRAIN

The moisture content of stored grain is one of the most important factors in relation to its susceptibility to insect attack. The insects that breed in stored grain are dependent on their food supply for the moisture required to carry on their life processes in a normal manner. A high moisture content in grain is favorable to a rapid increase in the number of insects breeding in it. If, however, the moisture content of the grain is too low, the water required for carrying on the vital life processes can be obtained only by breaking down the food reserves of the body. Loss of weight results from this consumption of the reserve body tissues, and the insects eventually die. The water requirements naturally differ with each species of insect, and some are able to subsist on drier grain than others. It has been discovered, however, that the rice and granary weevils are unable to live in wheat that has a moisture content of 8 percent or less and that a much higher moisture content is required for them to breed normally. Wheat

grown in the Pacific Northwest is usually harvested with a moisture content of 8 or 9 percent, and it is singularly free from insect damage. By drying high-moisture-content grain its susceptibility to insect attack can be greatly reduced. Exposure of the grain to high temperatures in driers also kills the insects that infest it. A temperature of 140° F. for 10 minutes is fatal to all grain-infesting insects that are actually exposed to it. However, since the grain in which the insects are living affords a certain amount of protection, the air temperatures in the drier should be higher or the exposures longer than those mentioned.

Grain driers of various kinds and types are on the market, but most of them are similar in principle, in that warm air is forced through layers of grain. Provision is also made for cooling the grain afterward by forcing cool air through the grain. According to Hurst and Black—[2]

> An air temperature of 180° F. is considered as the maximum allowable temperature for drying wheat without injury to the milling and baking qualities, and unless the temperature of the drying air can be accurately controlled it is advisable to operate at a slightly lower temperature. This is especially true if the grain is high in moisture content. Tests have shown that the germination of wheat, rye, oats, and buckwheat apparently was not impaired by artificial drying with heated air at 120°, 140°, or 160°.

FUMIGATION OF GRAIN

When other methods of treating grain to control insects are ineffective or for some reason cannot be employed, fumigtaion must be resorted to. A number of fumigants that are effective, relatively cheap, and simple to apply are available for use in terminal elevators. There are, however, certain factors affecting the efficiency of these fumigants that should be understood if the best results are to be obtained.

Fumigants kill insects by asphyxiation or by preventing the body tissues in some way from utilizing oxygen in the normal manner. To be effective, therefore, the fumigant used must be so distributed through the grain that every insect is exposed to a concentration strong enough to kill it. This distribution is usually accomplished by introducing the fumigant into the grain stream as the bin is being filled, so that the ingoing grain will carry the fumigant along with it and distribute it uniformly throughout the bin. With some of the more volatile liquid fumigants this method of continuous application to the grain stream permits serious loss of the fumigant from vaporization and the carrying away of the vapors by the air displaced by the falling grain. This loss is accentuated when the fumigant is sprayed on the grain stream, since breaking the liquid up into a fine spray increases its rate of vaporization.

The prevailing air and grain temperatures also affect the loss of volatile fumigants applied to the grain stream. With high temperatures of air or grain, the vaporization of the liquid chemical is speeded up and the loss increased. The belief that grain cannot be satisfactorily fumigated if it is cool is not necessarily true. In fact, the greater loss from the rapid vaporization of volatile fumigants applied to warm grain as it is run into the bin may more than offset the greater susceptibility of insects at higher temperatures. It has been found that

[2] HURST, W. M., and BLACK, R. H. GRAIN DRYING AT A COUNTRY ELEVATOR. U. S. Dept. Agr. Cir. 127. 15 pp., illus. 1930.

excellent results can be obtained in the fumigation of elevator grain while the temperature of the grain is as low as 60° F., when the fumigant is applied to the grain stream. It is preferable, however, to fumigate by this method with a grain temperature between 65° and 70°. It is rarely necessary to fumigate grain with a temperature below 60°, as such wheat is not likely to be seriously damaged by insects.

The surface application of heavier-than-air fumigants is sometimes necessary for large bins of grain that cannot be easily moved. If the grain is warm, the fumigant applied to the surface will penetrate to the bottom in killing concentrations. If, however, the temperature of the grain is below 70°, the penetration of the fumigant is not entirely satisfactory.

A number of fumigants are available for use in terminal elevators, all of which can be depended on to give satisfactory results if properly applied. Information regarding these fumigants and directions for their use follow. Unless otherwise stated, the dosages and methods recommended apply equally well for all small grains.

ALL FUMIGANTS DANGEROUS [3]

In using fumigants, the operator should realize that any fumigant that is toxic to insects is also toxic to human beings and that it is necessary to take every precaution to avoid exposure to heavy concentrations of fumigants. No one should be allowed to handle fumigants alone. Gas masks are available which are equipped with specially designed canisters for removing dangerous vapors from the air that is breathed through them. **A special canister is required for use with each of the different fumigants, and it should not be taken for granted that any canister will afford protection against all gases.** Since the life of a canister is limited, care must be exercised to see that new ones are supplied whenever those in use show signs of weakness. Operators should become familiar with the use of a gas mask and, before entering concentrations of fumigants, should test the mask for possible leaks. In bins of the flat-bottom type, where it is necessary for workmen to shovel out the grain not removed by gravity, special precautions should be taken to see that no dangerous concentrations of gas are present when workmen enter the bin, unless they are wearing gas masks.

Before attempting to use a fumigant, the operator should familiarize himself with the recommended method of employing it and should acquaint himself with the precautions necessary for its safe application. In no case should an employee enter a bin that is being fumigated, either to apply the fumigant or for any other purpose. In all cases the fumigant must be applied from outside the bin. Serious consequences have resulted from workmen unnecessarily entering bins to apply fumigants.

HYDROCYANIC ACID GAS AS A GRAIN FUMIGANT

A granular crude calcium cyanide containing approximately 25 percent of available hydrocyanic acid, which is released slowly on exposure to atmospheric moisture, is an effective grain fumigant that

[3] In many places competent commercial pest-control operators, who are familiar with fumigation procedures and hazards, are available.

is suitable for use only in grain that can be turned into closed-top bins. Its use in open-top bins should never be attempted.

It has been found that the best results are obtained with a dosage of 25 pounds per 1,000 bushels of grain; however, in closed-top concrete or steel tanks a dosage of 10 pounds is ordinarily used and gives a satisfactory kill under most conditions. In wooden cribbed bins the customary dosage is 20 pounds per 1,000 bushels. In all cases double the prescribed dosage should be applied to the first and the last 500 bushels that enter the bin. Yellow corn, barley, and oats, as well as wheat, may be fumigated with calcium cyanide without damage to the grain, but white corn and polished rice would become spotted.

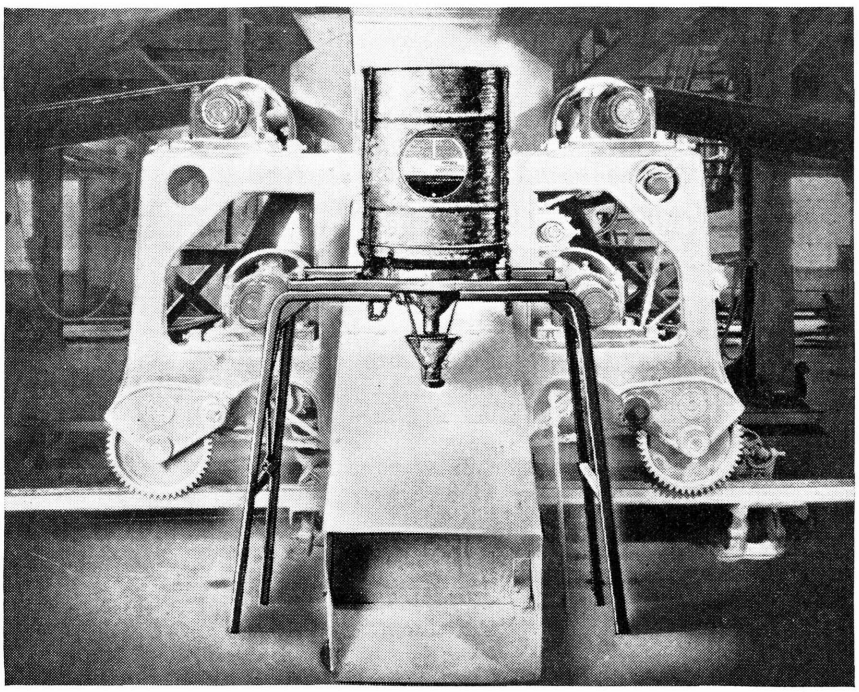

FIGURE 7.—Calcium cyanide applicator set over a tripper spout.

Specially designed, gravity-feed applicators are employed to introduce the calcium cyanide into the grain stream as the bin is filled. In terminal elevators, where the grain being turned passes through a tripper, the method of application shown in figure 7 is the most desirable, but, if necessary, the fumigant may be fed into the grain stream through a pipe. Calcium cyanide in all cases is fed into the grain stream through specially calibrated feed plugs, the size depending upon the rate of flow of the grain. Since hydrocyanic acid is deadly to human life, this fumigant should be handled with great care, and by one trained in its use. The operator should wear a gas mask when attending the applicator. Play safe. To fumigate a bin of grain, the cover of a 100-pound drum is first removed, together with the rubber gasket and the instruction leaflet that will be found there. The large funnel of the applicator is then attached tightly over the

opened drum by means of chains and hooks. The drum and funnel are then lifted and placed, funnel down, in the ring of the stand that has previously been assembled and set in place. By placing a piece of canvas around the bottom of the tripper spout the carrying of particles of calcium cyanide up into the head house along with the grain dust will be minimized.

As soon as the grain begins to flow into the bin the operator opens the feed-plug slide that allows the calcium cyanide to run into the grain stream. All the plugs are provided with two holes, so the double dosage required for the first and last 500 bushels can be obtained by allowing the calcium cyanide to flow through both holes for the necessary time. Thereafter no special attention is required except to replace drums as they are needed. The operator should therefore keep away from the top of the bin while it is being filled, since the air displaced from the bin will carry some of the deadly gas. Bins should be fitted, if possible, with an outside vent to carry off the displaced air. In all cases it is essential also to keep all bin-house windows open during the application of the fumigant.

Treated grain should be allowed to stay in the bin at least 3 days before being moved. If grain is turned or loaded out less than 2 weeks after fumigation, care should be taken to see that the tunnel room is well ventilated.

Bins that have held grain fumigated with calcium cyanide should not be entered by workmen for some time after the grain has been removed unless forced ventilation can be employed, since dangerous concentrations of the gas may remain. If the bins are over 40 feet in height, and access is only from the top, the bottom slide should be left open and 25 to 50 bushels of wheat run through the bin, thus eliminating the necessity of sweeping the bin.

With calcium cyanide there is no fire or explosion hazard so far as the fumigant is concerned. It has been found that fumigations conducted with the recommended dosage of 10 pounds per 1,000 bushels of wheat, or double this dosage, have no effect upon the germination or the milling or baking qualities of treated wheat. It is not desirable, however, to subject to a baking test any flour milled from wheat fumigated less than 10 days previously, as traces of the gas affect the yeast action.

The calcium cyanide used for fumigating grain can usually be purchased locally, in 100-pound drums, for approximately 22½ cents per pound.

CHLOROPICRIN

Chloropicrin, one of the war gases, has been found useful for the treatment of elevator grain. It is a colorless or slightly yellowish liquid a little more than 1⅔ times as heavy as water. It boils at 233.6° F. and on exposure to air vaporizes slowly, forming a heavy vapor. At 77° and with a pressure of 760 millimeters the atmosphere saturated with chloropicrin vapor is 1.1458 times as heavy as air. The gas is nonexplosive and noninflammable as ordinarily used, is extremely toxic to insects and also to man, and, owing to its lachrymatory nature, has a very irritating effect on the eyes and respiratory passages.

Chloropicrin can be purchased in cylinders of from 1 to 100 pounds, at a cost of from $1.25 per pound for the 1-pound cylinder to 85 cents per pound for 100-pound lots f. o. b. the factory.

The fumigant is applied directly to the grain stream as the bins are being filled. A special applicator, consisting of a container with a valve and tube leading from the base into the tripper spout near the entrance to the bin, is used to apply the fumigant, the flow of which is regulated by the valve (figs. 8 and 9). If the rate at which the grain is flowing into the bin is known, it is a simple matter to make the proper adjustment of the valve.

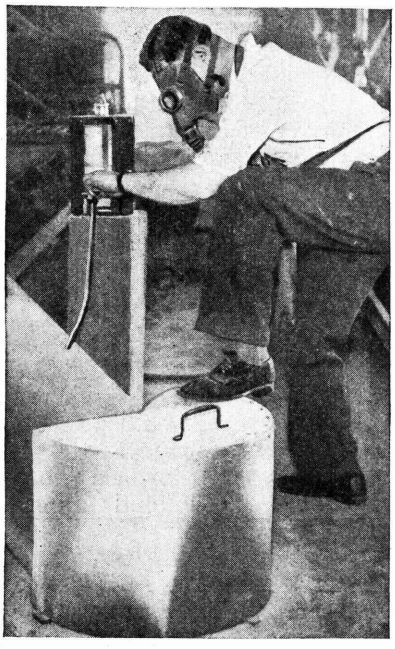

FIGURE 8.—Drip method of treating grain with chloropicrin, in which a gallon-jug type of applicator is used. The flow of the fumigant into the grain stream is regulated according to the speed at which the grain is run into the bin.

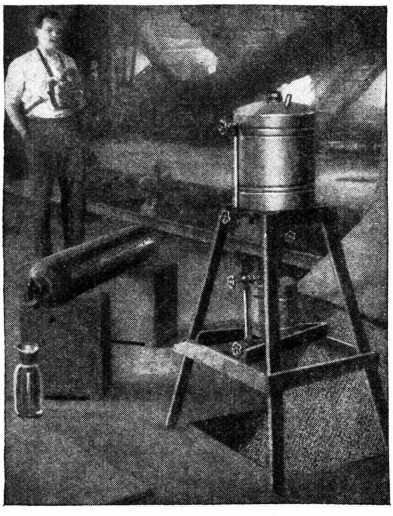

FIGURE 9.—Large type of applicator for treating grain with chloropicrin. The reservoir at the top holds 70 pounds of chloropicrin.

A dosage of 2 pounds of chloropicrin (or 3 pounds for oats) per 1,000 bushels, with an extra pound for the first and last 1,000 bushels, has been found to give highly satisfactory results.

While filling the applicator with chloropicrin and adjusting the flow of the fumigant, the operator must wear a gas mask fitted with a yellow canister designed to afford protection from the fumes.

For the comfort of the operators in the head house, the outside ventilators and the windows in the head house should be kept open during the application of the fumigant. Gas masks should also be available for any operator required to remain in the head house during the application of the fumigant. Upon completion of the treatment the ventilators and also the manhole and other openings should be closed, and the grain should be left undisturbed for at least 48 hours, after which time it can be turned.

The baking and milling qualities of the treated grain are temporarily seriously affected. If, however, the grain is well aerated, these deleterious effects pass off.

The vapors of chloropicrin have little effect on the germination of wheat at the dosages recommended if the moisture content of the grain is 12 percent or less. If the moisture content of the grain is higher than 12 percent some injury may result to the germination, the extent of the injury being proportional to the moisture content, the dosage, and the length of exposure.

ETHYLENE DICHLORIDE-CARBON TETRACHLORIDE MIXTURE

The ethylene dichloride-carbon tetrachloride mixture is an inexpensive, noninflammable fumigant that has proved very effective for the treatment of stored grain. It is made up of 3 parts by volume of ethylene dichloride and 1 part by volume of carbon tetrachloride, the latter ingredient being added to render the fumigant noninflammable. The resulting mixture is a colorless liquid with an odor resembling that of chloroform. It has no adverse effect upon the germination of grain, regardless of the dosage, exposure, or moisture content of the grain. The vapor has an anesthetic action when breathed in concentrated form. Although it is not so highly toxic as the fumigants previously mentioned, the operator should protect himself from the vapors with a suitable gas mask. The mixture weighs approximately 11 pounds per gallon and can be purchased in 55-gallon drums for approximately 6¼ cents per pound f. o. b. the factory.

In the fumigation of elevator grain the mixture should be used at the rate of 3 gallons per 1,000 bushels of grain, applied to the grain stream as follows: 1 gallon poured on the first 100 bushels run into the bin, followed by 2½ gallons poured on the last few hundred bushels of each 1,000-bushel draft or 4 gallons poured on the last few hundred bushels of each 1,500-bushel draft run into the bin, whichever is more convenient, the remaining portion of the dosage being sprinkled over the surface of the grain when the bin is filled. At this dosage it has been found effective at temperatures as low as 60° F. Fumigated grain should be left undisturbed for at least 72 hours after treatment.

CARBON DISULFIDE MIXTURES

Mixtures of carbon disulfide with other chemicals, such as carbon tetrachloride and sulfur dioxide, to reduce the fire hazard, are now being used extensively for the fumigation of grain. These mixtures consist of approximately 20 percent of carbon disulfide and 80 percent of carbon tetrachloride, by volume, to which may be added a small quantity of sulfur dioxide or other chemicals. When properly made, such mixtures appear to be relatively free from fire hazard. The layman should not attempt the manufacture of such mixtures, since the safety from fire hazard of the fumigant is dependent upon its proper preparation. Only mixtures the use of which has been sanctioned by fire insurance underwriters should be used. Mixtures of carbon disulfide and carbon tetrachloride, as ordinarily used, have no deleterious effects on the germination of sound grain. Operators should be reminded that the vapors of all such mixtures are toxic, and adequate gas masks should be worn while using such mixtures. The Division of Labor Standards, United States Department of Labor, warns that concentrations of 20 parts of carbon disulfide per million parts of air are dangerous.

A dosage of 1½ gallons of the mixture per 1,000 bushels of grain gives a good commercial kill. For the best results, it should be applied in proportionate doses to every 1,500-bushel draft of grain as the bin is being filled, in somewhat the manner described for the ethylene dichloride-carbon tetrachloride mixture. An application schedule for a 6,000-bushel bin with a dosage of 1½ gallons per 1,000 bushels is as follows: 2 gallons applied with a sprinkling can to the grain stream toward the end of the first, second, and third 1,500-bushel drafts, respectively, and the remaining 3 gallons toward the end of the last 1,500-bushel draft. An exposure period of at least 72 hours should be allowed.

Reliable mixtures of this type can be purchased for $2 per gallon f. o. b. the factory. Owing to the explosive and inflammable nature of its vapor when mixed with air, carbon disulfide should never be used alone in either terminal or country elevators.

ETHYLENE OXIDE-CARBON DIOXIDE MIXTURE

Ethylene oxide, in a mixture with carbon dioxide in the form of "dry ice," has proved useful as a fumigant for elevator grain. It is somewhat more expensive and laborious to apply than the other fumigants discussed in this bulletin, but it has been found highly effective for the treatment of grain. It leaves no odor on grain and does not affect the milling and baking qualities of wheat. It does, however, reduce the germination of wheat somewhat.

Ethylene oxide at ordinary temperatures is a colorless gas. At low temperatures it is a mobile, colorless liquid, boiling at 50.9° F. The concentrated vapors of ethylene oxide are inflammable, but concentrations up to 3½ pounds per 1,000 cubic feet of space are nonexplosive and noninflammable. When ethylene oxide is mixed with carbon dioxide in certain proportions a noninflammable fumigant is produced.

The process of fumigation consists of mixing 3 pounds of liquid ethylene oxide and 30 pounds of carbon dioxide in the solid form and introducing this quantity into the grain for each 1,000 bushels at the point where it enters the bin. The mixture is carried down with the grain and becomes thoroughly distributed throughout the grain column, where it soon changes to a vapor that kills all insects present. An exposure period of at least 72 hours is desirable.

Carbon dioxide in solid form has a temperature of −110° F. On exposure to air it slowly changes from a solid to a vapor or gas. For fumigation purposes a special type is used that is not compressed so much as the ordinary type. It is about as hard as chalk and is very easily crushed. If necessary, the ordinary kind can be used. Since it evaporates at the rate of about 5 percent by weight per day in the insulated boxes in which it is shipped, it should not be ordered ahead of time, but only after the ethylene oxide is on hand, so that the fumigation can proceed as soon as the solid carbon dioxide arrives. Somewhat more than the quantity needed for the fumigation must be purchased in order to allow for loss by sublimation. Since the solidiffed form of the gas has a temperature of −110° F. it should not be handled with bare hands. If carelessly handled, it is likely to blister the skin.

The carbon dioxide is prepared for use by being broken into small pieces with a sledge, spade, or ice pick in a wooden, open-end box, from

which it can be shoveled easily into the pails or other containers in which the mixture is carried to the grain. The ethylene oxide, which is obtained in liquid form in steel cylinders or tanks, is poured over it in the proportion of 1 pound to each 10 pounds of the solid carbon dioxide. The ethylene oxide may be measured out of the cylinder by use of a gage, or weighed out by placing the cylinder on a platform scale (fig. 10). The latter method is much quicker and more satisfactory. The ethylene oxide liquid can be forced out of the tank or cylinder by air pressure created by a small bicycle pump.

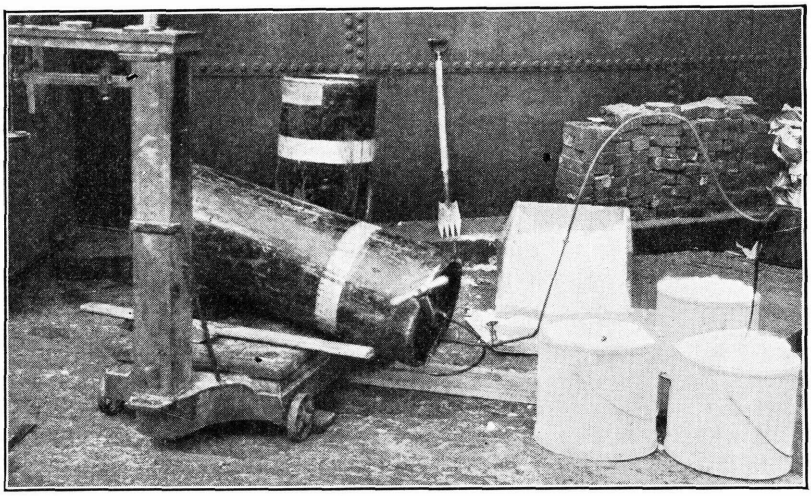

FIGURE 10.—Ethylene oxide being weighed out of a cylinder on a platform scale into cans of crushed "dry ice." A hand pump is used to increase the pressure in the cylinder sufficiently to force out the liquid ethylene oxide.

The mixture should be stirred a little so that all the liquid will be taken up by the carbon dioxide. A small quantity of bran or elevator dust placed in the pail before the carbon dioxide is put in will prevent the collection of free liquid in the bottom of the pail. To minimize loss by evaporation, the material should be mixed just before it is to be used. To avoid danger from fire and from exposure of workmen to dangerous concentrations of the fumigants, the chemicals must always be mixed outdoors.

The mixture is carried to the bin floor of the elevator, where it should be applied without delay by being shoveled into the grain stream as it is entering the bin. Spreading the mixture on the stream of wheat traveling on the belt conveyor would result in the loss of considerable fumigant before it reached the bin and is not a desirable practice. If the speed at which the grain is being run into the bin is known, it is a simple matter to figure out the rate at which the fumigant should be applied in order to obtain a dosage of 33 pounds of the mixture per 1,000 bushels of grain. For example, if the wheat is run into the bin at the rate of 12,000 bushels an hour, a 33-pound batch of the fumigant should be fed into the grain stream during every 5-minute period.

To compensate for leakage at the bottom and top of a bin, the dosage for the first 1,000 bushels and the last 500 bushels is made

proportionally greater than that for the rest of the bin. For example, in a 15,000-bushel bin, 66 pounds of the mixture is used for the first 1,000 bushels and 33 pounds of the mixture for the last 500 bushels. The dosage for the rest of the bin should be made slightly less than 33 pounds of the mixture per 1,000 bushels of grain in order to have an average of 33 pounds per 1,000 bushels for the entire bin.

Ethylene oxide can be purchased in 75- or 195-pound cylinders at a cost of 42 cents a pound, f. o. b. the factory. The cost of solid carbon dioxide is approximately 3 cents per pound, plus freight charges. Allowance must also be made for loss in weight from sublimation between the time of shipment and the time of use.

Where the bin is open at the top it is desirable to cap off the grain with a layer of the ethylene oxide-carbon dioxide mixture in order to insure a perfect kill in the upper layer of grain. As an illustration, a bin having a cross-section area of 200 square feet should receive an extra 66 pounds of the mixture as a top covering. It is also desirable to fill such a bin only to within 10 or 12 feet of the top so that a pocket of air will be present between the surface of the grain and the top of the bin, thus preventing excessive loss of the fumigant.

When the fumigant is applied by being shoveled into the grain stream, it will be found convenient to dump the mixture into an open-end box placed near the mouth of the bin. This insures a better mixture and makes it easier to shovel it into the bin. In applying the fumigant by this method the operator unavoidably inhales more or less of the gas unless a suitable gas mask is worn. As prolonged exposure to the fumes is likely to cause severe nausea, particularly in the presence of a heavy dust, men assigned to the task of shoveling the mixture into the grain must be equipped with adequate respiratory protection to prevent the severe nausea caused by exposure to the vapors. Should an employee become nauseated from too long exposure to the fumes, the discomfort is usually temporary.

RESIDUAL ODORS OF FUMIGANTS ON GRAIN

In the fumigation of grain the possibility of imparting residual odors to grain is a matter of great concern. It is well known that certain chemicals leave odors that are difficult to remove. Standard brands of the fumigants discussed in this bulletin can, however, be used without fear of contaminating grain. It sometimes happens that a sample of fumigated grain milled in an experimental mill carries a slight odor through to the finished products, whereas the odor is lost by passage of the same grain through the long milling stream of a commercial mill.

DUSTS OF LITTLE VALUE IN PROTECTING STORED GRAIN

From time to time attempts have been made to popularize the admixture of various dusts, such as lime, finely ground sand, etc., with stored grain to protect it from the attack of insects. Careful investigation has shown that for the protection of grain that is in a condition susceptible to insect attack such dusts are of little value unless the dust is of a poisonous nature, in which case its use for the treatment of grain intended for food would be out of the question.

TREATMENT OF GRAIN IN COUNTRY ELEVATORS

Grain stored in country elevators (fig. 11) cannot be cared for as efficiently as it can be in terminal elevators, and greater care must be exercised in order to prevent losses from insect damage. The bins in such elevators are usually of the wooden crib type, which are difficult to fumigate and, owing to the nature of their construction, harbor many insects that infest grain placed in them for temporary storage.

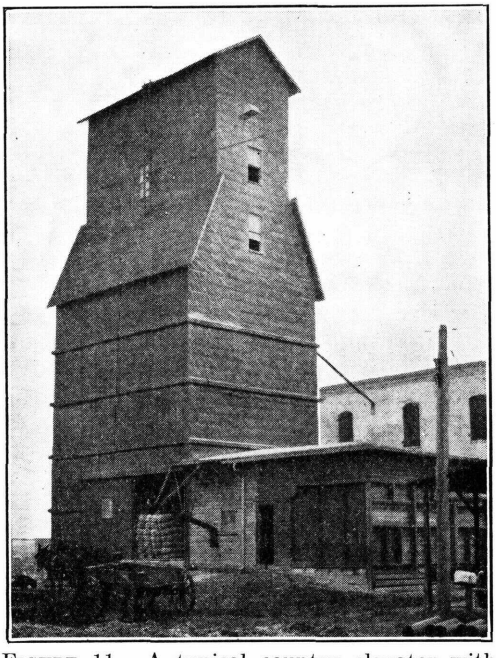

FIGURE 11.—A typical country elevator with wooden cribbed bins. Unless these small elevators are kept clean and fumigated, they serve as a constant source of infestation to grain placed in them for temporary storage. The cribbing of the bins forms an ideal situation for the establishment of insect infestations.

Where small lots of grain are received daily it is often desirable to treat partially filled bins after each new load is added. Heavier-than-air gases, such as chloropicrin, the ethylene dichloride-carbon tetrachloride mixture, or the carbon disulfide-carbon tetrachloride mixture, can be used, the fumigant being applied evenly over the surface of the grain. The regular dosage per 1,000 bushels recommended for terminal elevator fumigation should be applied for every 1,000 bushels added to the bin.

For the fumigation of an entire crib bin after it is filled, any of the fumigants recommended for use in terminal elevators can be used if the bin has a closed top. Because of the leakage factor in wooden crib bins, the dosage should be double that recommended for terminal elevator bins.

If the bins are open at the top—a condition common in many country elevators—calcium cyanide should not be used, but any of the other fumigants can be employed.

At times when country elevators are empty it is desirable to take measures to destroy the infestations that have become established in the cribbing of the bins and in accumulations of waste grain. In addition to a thorough clean-up, the fumigation of the building as a whole is recommended. For this purpose calcium cyanide (containing 25 percent hydrocyanic acid) has proved useful. This material and the gas evolved from it are extremely dangerous, however; if it is used, the precautions given on pages 10 to 12 of this bulletin should be carefully observed. A dosage of 3 pounds per 1,000 cubic feet of space will give excellent results and will insure the eradication of many infestations that have become established. In many cases such a

treatment will make it unnecessary to fumigate incoming grain for some time afterward. Usually infestations already established in the country elevators cause more trouble than the infestations that are likely to be brought in with grain loads.

In fumigating the empty elevator as a whole, the calcium cyanide should be divided so that proportionate quantities can be thrown into every bin and a proper quantity scattered in the head house and tunnel room or pit. The fumigator must wear a gas mask while applying the calcium cyanide. If the tunnel room or pit can be sealed off and it is not necessary to go through it on the way out, the calcium cyanide should be applied there first, the room sealed, and the bins and head house treated next. To obtain the best results the entire building should be well sealed to hold the gas. Precautions should be taken to see that nobody is allowed to enter the building during the course of the fumigation.

After an exposure period of 24 to 36 hours, the building should be opened up and well ventilated. In opening the building the workmen must wear gas masks, since the gas is fatal to human life if breathed in concentrated form. **A gas mask should always be worn by anyone entering a bin which has been fumigated, until it is certain that all traces of gas have disappeared.**

The residue from calcium cyanide is harmless and need not be cleaned out of the bins.

TREATMENT OF GRAIN IN WAREHOUSE STORAGE

In some parts of the country warehouse storage of bagged grain is practiced. Such storage may be used alone or in conjunction with elevator storage. When it is desired to fumigate warehoused, bagged grain, it may be treated without handling by fumigating the entire room or building, provided the building is of modern concrete or brick construction. If the building is of any other type of construction, individual lots of grain can be fumigated under tarpaulins.

For the fumigation of a modern tight warehouse of concrete or brick construction, filled with bagged grain, the use of methyl bromide is recommended. Methyl bromide has remarkable powers of penetration through large stacks of bagged grain and has no deleterious effects on the germination or quality of the grain. It cannot be used successfully in loosely constructed buildings. It is relatively cheap, is highly toxic to insects, is noninflammable, is relatively stable chemically, has low water solubility, and can be used at comparatively low temperatures. It has the disadvantage of lacking a distinctive odor at concentrations toxic to man, so its presence is not readily detected, and its action is more or less insidious. Its vapors have a slightly persistent odor approaching chloroform. It can, however, be handled with comparative safety by anyone familiar with its properties and experienced in the handling of fumigants. It is a colorless liquid which boils at 41.1° F. Its molecular weight is 94.94, and its specific gravity is 1.732. At ordinary temperatures it is a gas, 1 pound of which occupies 3.98 cubic feet. As compared with air, its specific gravity is 3.27 at a temperature of 32° and a pressure of 760 mm. It is obtainable in cylinders containing 10, 50, or 150 pounds net or in 1-pound cans. In 50-pound cylinders it is quoted at 65 cents per pound, f. o. b. the factory.

In preparing a warehouse or storage room for fumigation with methyl bromide, the entire building should be closed as tightly as possible, all windows should be tightly wedged and sealed and any broken panes replaced; loosely fitting window sashes should be sealed with paste and paper, or "puttied up" with a mixture of flour and oil; doors should be sealed in a similar manner. After the warehouse has been closed and everybody has left the building, the fumigant is applied through the same type of piping system used for the application of liquid hydrocyanic acid. Flexible copper tubing, three-eighths inch in diameter, leading from a manifold on the exterior of the building, is fastened along the ceiling of the warehouse. A spray nozzle is provided for every 10 to 15 thousand cubic feet of space.

In applying the methyl bromide, the natural pressure of the gas in the cylinder is usually increased, by the application of air pressure, to 150 pounds. Each cylinder contains a siphon tube, so that it may be emptied without inverting the cylinder. The siphon tube is connected to the manifold by the single outlet and the valve opened. The pressure will force the gas from the cylinder into the fumigation lines at the rate of about 10 pounds per minute. In cool weather it is sometimes necessary to build up the pressure in the cylinders a second time with compressed air in order to speed up the emptying of the cylinder and the application of the gas. A three-way connection between the cylinder, the manifold, and the air compressor will facilitate this operation. For the fumigation of large warehouses the 150-pound cylinders will usually be found more convenient. In the application of the gas, care should be taken that the connections between the cylinders and the manifold are tight, so that leaks will not endanger the operator.

A dosage of 1 pound of methyl bromide per 1,000 cubic feet of space has been found to give entirely satisfactory results if the warehouse has been made sufficiently tight.

An exposure of from 16 to 24 hours should be allowed, after which the building may be opened for aeration. In opening up the warehouse, workmen must wear gas masks equipped with a canister designed to protect against the vapors of methyl bromide.

According to the manufacturers of methyl bromide, masks equipped with the recommended canister are satisfactory for a maximum of 8,000 parts per million (2 pounds of methyl bromide per 1,000 cubic feet) for a period not exceeding 20 minutes.

Under ordinary conditions the warehouse will air out rapidly. A halide leak-detector lamp can be used to indicate whether dangerous concentrations of the gas remain in a building. If the color of the flame of the lamp is deeper than a light green, it denotes the presence of dangerous concentrations of the gas.

The United States Public Health Service published "Preliminary Recommendations to Fumigators Using Methyl Bromide or Mixtures Containing Methyl Bromide as a Fumigant" on May 16, 1938. All persons interested in using this fumigant should obtain copies of this leaflet. This publication contains the warning that, "**While methyl bromide is less toxic to man than certain other fumigants, all persons fumigating with methyl bromide or mixtures containing methyl bromide, or persons entering fumigated rooms, cars, or sheds to open ventilators or to unload fumigated materials, observe precautions used**

with other toxic fumigating gas. Experience indicates that adequate precaution will obviate danger of injury by this gas."

TREATMENT OF BAGGED GRAIN UNDER TARPAULINS

In warehouses that are too loosely constructed for successful fumigation it is customary to fumigate individual stacks of bagged grain under a gastight tent or fumigation blanket. This method of treating grain is particularly popular in California, where much of the grain is stored in bags in warehouses. The tent or tarpaulin should be of

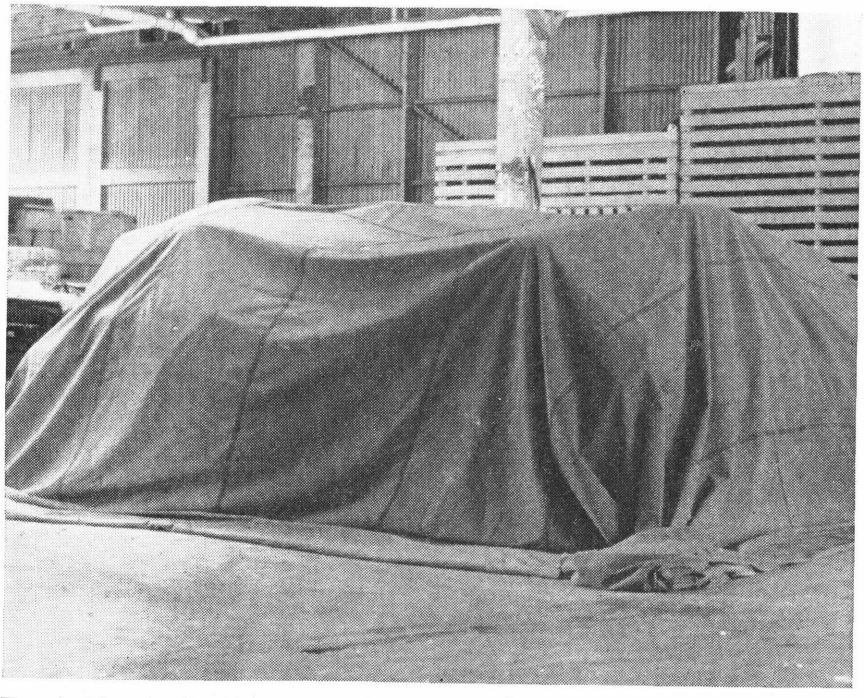

FIGURE 12.—A pile of bags covered with a rubberized tarpaulin ready for fumigation. Note that bags placed edgewise at each end of the top of the pile form a free air space for better diffusion of the fumigant. The edges of the tarpaulin on the floor should be weighted down to prevent loss of gas by leakage.

rubberized cloth or other material that will not permit the gas to leak out. The size of the pile to be treated will depend upon the size of the tarpaulin. In figure 12 is shown a stack of bags covered with a tarpaulin and ready for fumigation. The edges of the tarpaulin should be weighted down carefully to prevent leakage of gas from around the base of the stack. Provision is made for an air dome at the top of the stack by placing two sacks edgewise about 4 feet apart. This air dome will provide free air space to permit diffusion of the gas. In many cases smaller piles of bags are used, so that the fumigant will have a better chance to penetrate throughout the stack.

According to Mackie and Carter,[4] of the Department of Agriculture of California, the following fumigants, when used at the dosage given (per 1,000 cubic feet), have been found satisfactory for this type of work: Hydrocyanic acid, evolved from 3½ pounds of sodium cyanide; chloropicrin, 2 pounds; methyl bromide, 1 pound; and ethylene dichloride-carbon tetrachloride mixture, 17 pounds.

The same precautions must be exercised in handling these fumigants in tarpaulin fumigations as in other types of fumigation.

[4] MACKIE, D. B., and CARTER, W. B. PEST CONTROL IN RURAL WAREHOUSES AND SUGGESTED IMPROVEMENTS. Calif. Dept. Agr. Monthly Bul. 26: 275-293, illus. 1937.

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